KSÜ Tarım ve Doğa Derg 27 (1), 130-140, 2024
KSU J. Agric Nat 27 (1), 130-140, 2024
https://doi.org/10.18016/ksutarimdoga.vi.1278764

Determination of the Effects of Different Irrigation Strategies on Leaf Osmotic Potential and K and Ca Ion Concentrations in Red Pepper with Furrow and Drip Irrigation Methods

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ABSTRACT

A study was managed to identify the water stress effect on marketable yield, osmatic potential, and potassium (K) and calcium (Ca) ions for drip and furrow irrigated processing red pepper in the 2010 and 2011 growing seasons in Tarsus, Turkey. The treatments for drip irrigation; comprise full irrigation ($D_{FI1.0}$), deficit irrigation $D_{DI0.75}$, $D_{PRD0.5}$, $D_{FPRD0.5}$, and $D_{DI0.5}$; for furrow irrigation; full irrigation ($F_{FI1.0}$), fix alternative furrow ($F_{AF0.5}$) and PRD furrow ($F_{PRD0.5}$). $F_{AF0.5}$ and $F_{PRD0.5}$ received 50 % of the water applied to $F_{FI1.0}$. In $F_{AF0.5}$ the same furrows were irrigated while in $F_{PRD0.5}$ irrigated alternately. Irrigation methods and irrigation levels had a remarkable effect on the total yield of red pepper in both experimental years. Drip irrigation treatments manufactured higher red pepper yields than the furrow irrigation treatments. The maximum yield in the drip irrigation system was acquired from the $D_{FI1.0}$ treatment followed by $D_{DI0.75}$, $D_{DI0.5}$, and $D_{FPRD0.5}$ treatments. Though $D_{PRD0.5}$, $D_{FPRD0.5}$, and $D_{DI0.5}$ applied the same amount of water, $D_{PRD0.5}$ resulted in a higher yield. In furrow treatments, $F_{FI1.0}$ resulted in the highest yield followed by $F_{PRD0.5}$ and $F_{AF0.5}$. Water use efficiency (WUE) diminished with increasing the water amount for drip and furrow irrigation methods. While lower osmotic potential values were measured in full irrigation treatments in furrow and drip irrigation plots, higher osmotic potential values were determined in treatments where water stress was determined in both years. In both drip and furrow irrigation, the lowest Ca (%) values were obtained in full irrigation, while the highest Ca values were obtained in limited irrigation with water stress in the 2010 and 2011 years. K ion values were generally similar in the first and fourth pepper harvests in drip and furrow irrigation.

Irrigation

Research Article

Article History
Received : 07.04.2023
Accepted : 04.06.2023

Keywords
Pepper
Furrow
Drip irrigation
Osmotic potential
Partial root drying

Karık ve Damla Sulama Yöntemleriyle Kırmızı Biberde Farklı Sulama Stratejilerinin Yaprak Osmotik Potansiyeli ile K ve Ca İyon Konsantrasyonları Üzerine Etkilerinin Belirlenmesi

ÖZET

Tarsus, Türkiye'de 2010 ve 2011 yetiştirme sezonlarında damla ve karık sulama ile kırmızı biberin pazarlanabilir verim, osmatik potansiyel ve potasyum (K) ve kalsiyum (Ca) iyonları üzerindeki su stresi etkisini belirlemek için bir çalışma gerçekleştirildi. Damla sulama konuları; tam sulama ($D_{FI1.0}$), kısınıtlı sulama $D_{DI0.75}$, $D_{PRD0.5}$, $D_{FPRD0.5}$ ve $D_{DI0.5}$'ten oluşurken; karık sulama konuları; tam sulama ($F_{FI1.0}$), sabit alternatif karık ($F_{AF0.5}$) ve PRD karık ($F_{PRD0.5}$)'tan oluşmaktadır. $F_{AF0.5}$ ve $F_{PRD0.5}$, $F_{FI1.0}$ 'a uygulanan suyun %50'sini almıştır. $F_{AF0.5'}$ konusunda aynı karıklar, $F_{PRD0.5}$'te dönüşümlü olarak karıklar sulanmıştır. Sulama yöntemleri ve sulama seviyeleri, her iki deneme yılında da toplam kırmızı biber verimi üzerinde dikkate değer bir etkiye sahip olmuştur. Damla sulama konuları karık sulama konularına göre daha yüksek kırmızı biber verimi sağlamıştır. Damla sulama sisteminde en yüksek verim $D_{FI1.0}$ konusundan alınırken, ardından $D_{DI0.75}$, $D_{DI0.5}$ ve $D_{FPRD0.5}$ konuları izlemiştir. $D_{PRD0.5}$, $D_{FPRD0.5}$ ve $D_{DI0.5}$ konularına aynı miktarda sulama suyu miktarı uygulansa da, $D_{PRD0.5}$ konusunda daha yüksek verimle

Sulama

Araştırma Makalesi

Makale Tarihçesi
Geliş Tarihi : 07.04.2023
Kabul Tarihi : 04.06.2023

Anahtar Kelimeler
Biber
Karık
Damla Sulama
Ozmotik Potansiyel
Kısmi Kök Kurutma

sonuçlanmıştır. Karık uygulamalarında $F_{FI1.0}$ en yüksek verimle sonuçlanırken, bu konuyu $F_{PRD0.5}$ ve $F_{AF0.5}$ konualrı izlemiştir. Damla ve karık sulama yöntemlerinde su miktarı arttıkça su kullanım etkinliği (WUE) azalmıştır. Karık ve damla sulama parsellerinde yer alan tam sulama konusunda daha düşük ozmotik potansiyel değerleri ölçülürken, her iki yılda da su stresinin belirlendiği uygulamalarda daha yüksek ozmotik potansiyel değerleri belirlenmiştir. 2010 ve 2011 yıllarında hem damla hem de karık sulamada en düşük Ca (%) değerleri tam sulamada elde edilirken, en yüksek Ca değerleri su stresi yaşanan kısıntılı sulama konularında elde edilmiştir. Damla ve karık sulamada birinci ve dördüncü biber hasadında K iyon değerleri genel olarak benzer olmuştur.

To Cite : Akhoundnejad, Y., Sezen, S.M., & Dasgan, H.Y., (2023). Determination of the Effects of Different Irrigation Strategies on Leaf Osmotic Potential and K and Ca Ion Concentrations in Red Pepper with Furrow and Drip Irrigation Methods. *KSU J. Agric Nat 27*(1), 130-140. https://doi.org/10.18016/ksutarimdoga.vi.1278764

Atıf Şekli: Akhoundnejad, Y., Sezen, S.M., & Daşgan, H.Y., (2023) Karık ve Damla Sulama Yöntemleriyle Kırmızı Biberde Farklı Sulama Stratejilerinin Yaprak Osmotik Potansiyeli ile K ve Ca İyon Konsantrasyonları Üzerine Etkilerinin Belirlenmesi. *KSÜ Tarım ve Doğa Derg 27* (1), 130-140. https://doi.org/10.18016/ ksutarimdoga.vi. 1278764

INTRODUCTION

Pepper is an important vegetable that is grown in most countries around the world, and covers 1.93 million hectares (Penella & Calatayud, 2018). Pepper is consumed as a spice and only its fruit and only its fruit is used in cooking. According to data from 2017, the world's pepper production was 34 million tons (Penella & Calatayud, 2018). Sweet and paste pepper (*Capsicum annum L.*) is one of the most important vegetable products, especially in the Mediterranean region, where high efficiency and good fruit quality can be obtained in greenhouse conditions compared to open field conditions (Serret et al., 2018). Water resources are limited in the Mediterranean region, and there is increasing pressure on the use of these resources by other sectors such as domestic, urban, and industrial sectors, as well as irrigation. The agricultural sector is the largest consumer of water resources in the world, and it is important to use water efficiently (Sezen et al., 2017). The drip irrigation system can be used to apply irrigation water more efficiently and uniformly, resulting in significant savings in irrigation water usage, and maximizing water usage efficiency. Traditional irrigation scheduling is mainly based on monitoring the water content of the soil in the plant root zone. However, the internal water condition of the plant, which is located at the midpoint of the soil, plant, water, and atmospheric system, to both climate and soil water changes. Many published studies have shown that partial root-zone drying (PRD) increases the physiological mechanisms of osmotic pressure, stomatal conductivity, and enzyme activities in plants. The PRD system puts the plant in a continuous water retention state, drying out part of the plant root system while the remaining roots are well watered and develop better (Mousavi et al., 2010). Liu et al., (2006) reported that the mechanism of the PRD irrigation strategy increases the abscisic acid (ABA) and provides better yields than the products that are properly irrigated condition. Dodd (2009) compared the impacts of PRD and RDI (regular deficit irrigation) on the yield of varied crop species have indicated that dissimilar PRD and RDI plants were more subject to the potential decrease in yield. This risk could be reduced by near monitoring plant water status to prevent the development of heavy water stress that could notably diminish yield. The benefits of the PRD in comparison to RDI are also based on the increasing root growth and development and better control of vegetative vigor and assimilate partitioning (Mingo et al., 2004; Costa et al., 2007). This study aims to compare the effects of full, deficit irrigation (DI) regimes and partial root-zone drying (PRD) strategy under drip and furrow irrigation conditions through periodic measurements of K and Ca ion concentrations and leaf osmotic potential in red pepper (*Capsicum annuum* L.) leaves in Mediterranean climate conditions. In addition, the effects on marketable fruit yield, WUE, and IWUE of red pepper under furrow and drip irrigation conditions were compared under deficit irrigation, partial root-zone drying (PRD), and full irrigation conditions.

MATERIAL and METHOD

Experimental site, soil description, and climate

The field experiment was managed for 2 years (2010 - 2011) at the Tarsus Soil and Water Resources Unit of Alata Horticultural Research Institution (37°01′N and 35°01′E and altitude 60.0m above sea level), in Topcu, Tarsus, Turkey. The soil of the experimental field is clay loam clay texture with a relatively high water-holding capacity. The available soil water holding capacity of the experimental site was determined 120 mm in a 0.60 m soil profile. The soil water content at field capacity ranged from 0.29 to 0.37 g g^{-1} and wilting point ranged from 0.15 to 0.23 g g^{-1} on a dry weight basis for the experimental area. In the effective root zone, soil water contents at the field capacity and permanent wilting point are 284 and 164 mm, respectively. The dry soil bulk densities varied from 1.44 to 1.45 g cm^{-3} throughout the 60 cm soil profile.

The experimental area has a well-specified typical Mediterranean-type climate. Average the average yearly rainfall is 616 mm, and 54% of whole falls during the winter months. Considering long-term climatic information (1952-2007), the yearly evaporation, yearly average temperature, and yearly relative humidity of the region were 1490 mm, 17.8 °C, and 70.66%, respectively. The seasonal (April to October) mean rainfall during the 2010 and 2011 growing seasons are 165 and 172 mm, respectively.

Experimental design and treatments

The experiment was set out in a completely randomized block design with four replications for drip and furrow irrigation experiments. In drip irrigation, the first treatment ($D_{FI1.0}$) which is considered full irrigation, is the required amount of water to complete field capacity in the upper 60 cm soil depth when 25% of the soil available water is used. Also, drip treatments comprised deficit irrigation ($D_{DI0.75}$, $D_{DI0.5}$) and partial root drying ($D_{PRD0.5}$ and $D_{FPRD0.5}$). $D_{DI0.75}$ and $D_{DI0.5}$ received 75 and 50% of $D_{FI1.0}$, $D_{FPRD0.5}$ received 50% of $D_{FI1.0}$ irrigation permanently from one side of the crop row; $D_{PRD0.5}$ received 50% of $D_{FI1.0}$ water alternately from the lateral.

In furrow treatments, the ($F_{FI1.0}$) treatment which is considered as a full irrigation, is the required amount of water to complete to field capacity in the 60 cm soil depth when 40% of the soil available water is used. Deficit irrigation treatments comprised fixed alternate furrow ($F_{AF0.5}$) and PRD furrow ($F_{PRD0.5}$) in the furrow irrigation. $F_{AF0.5}$ and $F_{PRD0.5}$ received 50% of the water applied to $F_{FI1.0}$. In $F_{AF0.5}$ the same furrows were irrigated while $F_{PRD0.5}$ irrigated alternate furrows.

In drip-irrigated plots, laterals were settled in each plant row for $D_{FI1.0}$, $D_{DI0.75}$, and $D_{DI0.5}$ treatments, and inline emitters with a discharge rate of 2.3 L h^{-1}were spaced at 20 cm intervals on the lateral line (Sezen et al., 2006). In the $D_{PRD0.5}$ treatment plots, two drip laterals were settled out 20 cm away from the plant row. In the $D_{FPRD0.5}$ treatment plots, a single lateral was placed 20 cm away from the plant row. The system was operated at 100 kPa during the growing season. The control unit of the system occurs of a pump, gravel, and disk filters, a flow meter, control valves, a fertilizer tank, and pressure gauges.

The amount of irrigation water was computed based on the pre-irrigation soil water (Wi) in the measured soil profile according to the following equation (Eq. (1)):

$$I = (W_{FC} - W_i).\gamma . D. A$$

where I is the amount of irrigation water (m^3); WFC is the soil water at field capacity; γ is the soil bulk density (g cm^{-3}); D is the soil depth (0.6 m), and A is the area of the plot (m^2).The seasonal ET value was calculated using a water balance method expressed by Allen et al. (1998). WUE and IWUE values were calculated as the marketable yield of red pepper divided by seasonal ET and total irrigation during the all-growing season in 2010 and 2011 (Sezen et al., 2019).

Agronomic practices

Seedlings of Capsicum annuum (Karaisalı), a variety widely used in the region, were gently transplanted into the plots on 15 April 2010 and 19 April 2011, respectively in the first and second year of the study. Karaisali pepper is a local cultivar that originated from Adana city. The cultivar has capita-type pepper fruit. The fruit has a flabby and cylindrical form with a deep green color; the ripe fruit has red color. Thick flesh, good aroma, and sweet taste properties are appropriate for fresh table consumption in immature and mature stages in the local region. This cultivar is also extensively used for pepper paste manufacture in the area by the local people. The plants were grown in seven 70 cm spaced rows in each plot with 25 cm spacing in each row. Each plot had sizes of 10m long and 7 plant rows (4.9 m) in width with 280 plants per plot (5.7 plants m^{-2}).

All treatment plots received the same amount of total fertilizer. Preplant manure was applied at a rate of 20-30 tons per hectare in a manner that soil organic matter content was provided over 2%. The following fertilizer program was applied in the experiment at planting: 200 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, 250 kg ha^{-1} K_2O, 100 kg ha^{-1} CaO, and 50 kg ha^{-1} MgO. The total amount of P_2O_5 fertilizer and the remaining amount of fertilizer was applied through fertigation and began 3 weeks after transplanting. In each application, 1/6th of the above-mentioned fertilizer was applied for 3 weeks until the production of green fruit pepper. Also, microelements (Mn, Zn, Cu, B, and Mo) were applied at a rate of 5 kg ha^{-1}. Microelements were applied at 3 different times starting 3 weeks after transplanting, second during the green fruit formation phase, and third application at the red pepper formation phase (Salk et al., 2008).

The harvest area in each sub-plot was 28.0 m^2 (five rows, each 8 m in length). Mature red peppers were harvested six times in 2010 and seven times in 2011. The first collection was performed on August 02, 2010 (109 DAT: days after transplanting) and the final collection was performed on November 04, 2010 (203 DAT); the corresponding figures for the second year were July 19, 2011 (91 DAT) and November 03, 2011 (198 DAT), respectively.

Measurement of Leaf Osmotic Potential

As a physiological response when plants are exposed to water stress cells undergo osmotic regulation. In this case, the production of water-soluble organic substances usually sugars and amino acids is increased or there may be an accumulation of ions such as K and Ca. This osmotic regulation, which also ensures the preservation of turgor in the plant, was measured in the leaves of red pepper plants grown on different irrigation treatments in drip and furrow irrigation experiments. Thus, the effect of water stress on plants that applied the PRD irrigation strategy with the classical drip and furrow methods with limited irrigation was presented comparatively. In both drip and furrow irrigation, leaf samples were taken before irrigation applications and the dates are indicated in the text. For this purpose, mature leaf samples were taken periodically during the experiment and the "osmotic potential" values were measured with the help of the "osmometer" device (Turner & Buirchell, 2007).

Determination of K and Ca Ion Concentrations in Leaves

In drip and furrow irrigation plots, osmotic regulation occurs with the accumulation of K and Ca elements as a reaction of plants to water stress, especially in deficit irrigation treatments. For this purpose, the concentrations of K and Ca elements at different irrigation levels were determined in leaf tissues. Dried and ground leaf samples were burned at 550 °C and dissolved in 3.3% (v/v) HCl and elemental concentrations were read in an atomic absorption spectrometer (Varian 220 FS) in emission mode (Dasgan et al., 2009).

Treatments were compared using Duncan's multiple test. Additionally, the values in the charts are given as mean ± Standard errors.

RESULTS and DISCUSSION

Irrigation, seasonal ET, Marketable Yield, WUE, and IWUE

To accomplish a uniform plant stand, a total of 55 mm in 2010 and 20 mm in 2011 of irrigation water was implemented same to all treatment plots. In drip irrigation plots, the first treatment irrigation was implemented on June 07, 2010, and May 18, 2011. The last irrigation practice was provided on October 25, 2010, and October 21, 2011. The sum of total irrigation water applied altered from 385 mm to 715 mm in 2010 and 395 mm to 770 mm according to the treatments in drip irrigation plots Table 1). Irrigation frequencies in the drip irrigation treatments ranged from 4 to 9 days in 2010 and 4 to 8 days in 2011. Drip irrigation treatments were irrigated 22 times in the first year and 25 times in the second year.

In the furrow plots, the first treatment irrigation was implemented on June 11, 2010, and June 07, 2011. The last irrigation practice was implemented on October 28, 2010, and October 21, 2011. The sum of irrigation water applied ranged from 429 mm to 823 mm in 2010 and 452 mm to 884 mm depending on the treatment (Table 1). Irrigation frequencies ranged from 6 to 13 days in 2010 and from 6 to 12 days in 2011 in the furrow treatments. Furrow irrigation treatments were irrigated 16 and 18 times in the 2010 and 2011 seasons, respectively.

Seasonal evapotranspiration (ET) by red pepper ranged from 515 mm in $D_{PRD0.5}$ to 809 mm in $D_{FI1.0}$ treatment in 2010; and 539 mm in $D_{PRD0.5}$ to 824 mm in $D_{FI1.0}$ treatment in 2011 (Table 1). The ET values raised with the increasing amount of irrigation under furrow and drip irrigation treatments. PRD treatments in the drip irrigation systems ($D_{FPRD0.5}$, $D_{PRD0.5}$) showed slightly lower ET than $D_{DI0.5}$ treatment even though receiving the same amount of water.

WUE and IWUE values were notably impacted by irrigation treatments and irrigation methods (Table 1). WUE values varied from 5.46 kg m^{-3} in $D_{FI1.0}$ to 7.14 kg m^{-3} in the $D_{PRD0.5}$ in 2010 and varied from 5.79 kg m^{-3} in $D_{FI1.0}$ to 7.48 kg m^{-3} in the $D_{PRD0.5}$ in 2011 in drip treatments. $D_{PRD0.5}$ resulted in the highest WUE values in drip treatments. In furrow treatments, WUE values varied from 3.84 to 5.80 kg m^{-3} in 2010; 4.23 to 4.82 kg m^{-3} in 2011. IWUE values ranged from 6.18 kg m^{-3} in $D_{FI1.0}$ to 9.55 kg m-3 in $D_{PRD0.5}$ treatment in the 2010 and varied from 6.21 kg m^{-3} in $D_{FI1.0}$ to 10.20 kg m^{-3} in the $D_{PRD0.5}$ in the 2011 season.

Leaf Osmotic Potential

As a physiological response when plants are exposed to water stress cells undergo osmotic regulation. This osmotic regulation, which maintains the turgor state of the plant, was measured in the leaves of red pepper plants grown under different irrigation treatments in drip and furrow irrigation plots. For this purpose, the mature leaf samples that have completed their development periodically during the experiment were taken and the "osmotic potential" values were measured with the "osmometer" device in the laboratory. The first osmometer measurement was started on July 02, 2010, and the last measurement was made on September 29, 2010. The temporal variation of leaf osmotic potential in drip and furrow irrigation is given in Figures 1 and 2.

While lower osmotic potential values were measured in $D_{FI1.0}$ treatments, higher osmotic potential values were determined in $D_{DI0.5}$ and $D_{FPRD0.5}$ treatments, where water stress was determined in Figure 1. While lower osmotic potential values were measured at the beginning of the experiment, the osmatic potential values increased towards the end of the season.

While lower osmotic potential values were measured for $F_{FI1.0}$, increased water stress resulted in higher osmotic potential values, especially for $F_{AF0.5}$ treatment in Figure 2. Leaf osmotic potential values resulted in higher values under increasing stress conditions. Mullet ve Whitsitt, (1996) indicated that the mechanism of tolerance to water stress has been reported as "osmotic regulation" and protection of membranes in the cell.

Table 1. Yield, irrigation, ET, WUE, and IWUE values of red pepper in-furrow and drip irrigation treatments (2010, 2011)

Çizelge 1. Karık ve damla sulama uygulamalarında kırmızı biberde verim, sulama, ET, WUE ve IWUE değerleri (2010, 2011)

Years	Irrigation methods	Treatments	Seasonal irrigation (mm)	ET (mm) **	Yield (kg ha^{-1}) **	WUE (kg m^{-3}) **	IWUE (kg m^{-3}) **
2010	Furrow	$F_{PRD0.5}$	439	602 ± 17.15 b	34940 ± 64.42 a	5.80 ± 0.18 a	7.95 ± 0.10 a
		$F_{AF0.5}$	439	631 ± 11.21 b	31720 ± 127.80 b	5.03 ± 0.15 ab	7.22 ± 0.18 a
		$F_{FI1.0}$	823	928 ± 12.28 a	35590 ± 156.84 a	3.84 ± 0.20 b	4.32 ± 0.19 b
	Drip	$D_{PRD0.5}$	385	515 ± 9.40 d	36750 ± 147.20 c	7.14 ± 0.18 a	9.55 ± 0.18 a
		$D_{FPRD0.5}$	385	558 ± 5.85 c	34160 ± 91.29 d	6.12 ± 0.20 b	8.87 ± 0.09 a
		$D_{FI1.0}$	715	809 ± 11.56 a	44170 ± 148.55 a	5.46 ± 0.16 b	6.18 ± 0.13 c
		$D_{DI0.75}$	561	707 ± 14.49 b	40830 ± 147.20 b	5.78 ± 0.18 b	7.28 ± 0.10 b
		$D_{DI0.5}$	385	572 ± 9.31 c	34920 ± 147.20 d	6.10 ± 0.20 b	9.07 ± 0.18 a
2011	Furrow	$F_{PRD0.5}$	452	638 ± 10.23 c	30740 ± 91.29 b	4.82 ± 0.20 ns	6.80 ± 0.18 a
		$F_{AF0.5}$	452	663 ± 14.93 b	29320 ± 380.09 b	4.42 ± 0.15 ns	6.49 ± 0.12 a
		$F_{FI1.0}$	884	980 ± 9.97 a	41500 ± 204.12 a	4.23 ± 0.20 ns	4.69 ± 0.14 b
	Drip	$D_{PRD0.5}$	395	539 ± 7.14 d	40330 ± 204.12 b	7.48 ± 0.19 a	10.20 ± 0.21a
		$D_{FPRD0.5}$	395	572 ± 11.87 c	33760 ± 132.92 d	5.90 ± 0.20 b	8.55 ± 0.19 bc
		$D_{FI1.0}$	770	824 ± 7.63 a	47790 ± 204.12 a	5.79 ± 0.18 b	6.21 ± 0.18 d
		$D_{DI0.75}$	595	752 ± 11.35 b	47170 ± 142.83 a	6.27 ± 0.16 b	7.93 ± 0.14 c
		$D_{DI0.5}$	395	592 ± 16.05 c	35970 ± 203.47 c	6.08 ± 0.18 b	9.11 ± 0.13 b

Letters indicate significant differences at *$P < 0.05$ and **$P < 0.01$

Figure 2 showed that while lower osmotic potential values were measured for $F_{FI1.0}$, increased water stress resulted in higher osmotic potential values, especially for $F_{AF0.5}$ treatments. The temporal variation of leaf osmotic potential values for 2011 in drip and furrow irrigation treatments are given in Figures 3 and 4. The first osmometer measurement was started on June 07, 2011, and the last measurement was made on October 04, 2010.

In 2011, while the lowest osmotic potential values were measured for $D_{FI1.0}$ in drip irrigation, the highest values were determined for $D_{DI0.5}$ and $D_{FPRD0.5}$ treatments. While lower osmotic potential values were measured at the beginning of the experiment, osmotic potential values increased towards the end of the season in 2011 (Figure 3).

In 2011, while the lowest osmotic potential values were measured for $F_{FI1.0}$ in furrow irrigation, it resulted in the highest osmotic potential values for $F_{AF0.5}$. While lower osmotic potential values were measured at the beginning of the experiment in furrow irrigation treatments, the osmatic potential values increased towards the end of the season in 2011 (Figure 4). Physiological, biochemical, and molecular biological levels of the plant were investigated in PRD applications in different plants and, for example, potato crops showed positive physiological regulation due to osmotic adaptation (Su et al., 2020). Water stress occurs from the osmotic salinity of soil and water. (Lian et al., 2004). Under stress conditions, absisic acid (ABA) is produced and osmotic adjustment processes carry it to the leaves via the xylem (Schachtman & Goodger, 2008). The osmotic concentration in the leaves of plants is related to its osmotic potential. After the salt of the water decreases, the osmotic potential in the leaf is irrigated conditions (Saleh, 2012). Conversely, Alvares et al., (2012) reported that no osmotic adjustment was observed in plants submitted to water stress. The osmatic potential responds not only to water stress but also to other factors including cultivar, environment, soil type, and the relationships between canopy and root system, i.e. the resistance to water movement. Therefore, the water potential thresholds to schedule irrigation are site-specific (Garcia-Tejera et al., 2021).

K and Ca Ion Concentrations in Leaves

K and Ca ion concentrations in pepper were determined on the leaf samples taken in the first (August 02, 2010, and July 19, 2011) and fourth harvest (September 13, 2010 and September 05, 2011) periods in the 2010 and 2011 experimental years for furrow and drip irrigation (Figures 5-8).

In drip irrigation, the Ca ion values of 2010 were determined to be higher both in the first harvest and in the fourth harvest compared to the 2011 season. The highest Ca (%) values were determined for $D_{PRD0.5}$ in both trial years and the lowest Ca (%) values for $D_{FI1.0}$

treatment (Figure 5). Similar to drip irrigation, it was determined that Ca ion values in furrow irrigation in 2010 were higher both in the first harvest and in the fourth harvest compared to the 2011 season. In both experimental years, the highest Ca (%) values were determined for $F_{AF0.5}$ treatment, and the lowest Ca (%) values were determined for $F_{FI1.0}$ treatment (Figure 6).

In drip irrigation, the K ion values of both years were generally similar in the first and fourth harvests. In the 2010 and 2011 experimental years, the highest K (%) values were found in $D_{FPRD0.5}$, $D_{DI0.5}$, and the lowest K (%) values were in $D_{PRD0.5}$ (Figure 7). In the furrow irrigation treatments, the K ion values of both years were generally similar in the first and fourth harvests.

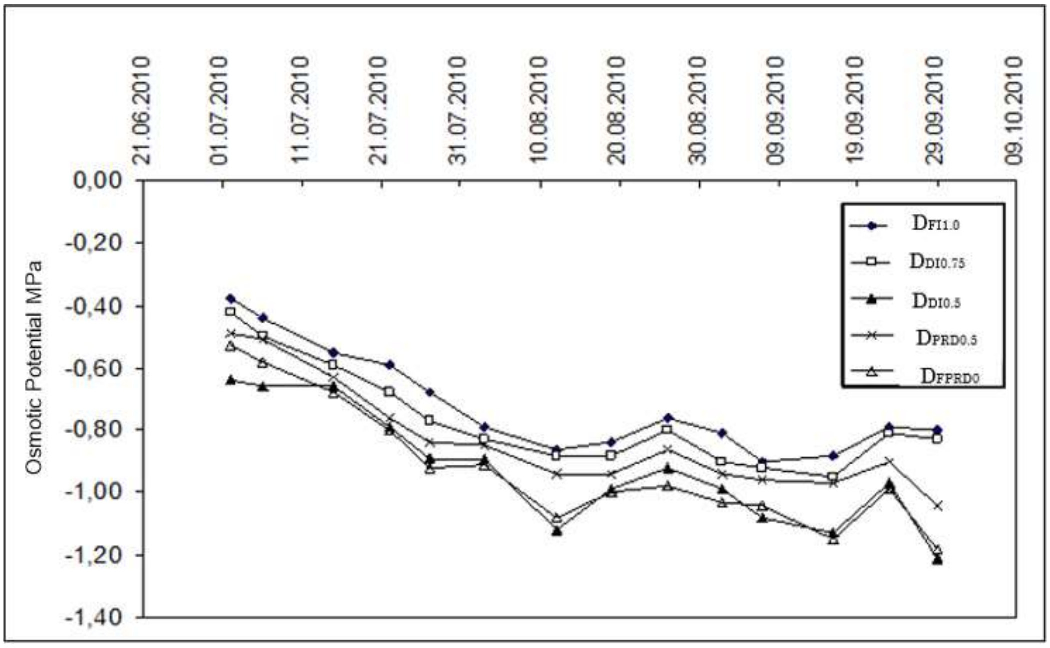

Figure 1. Temporal change of leaf osmotic potential in drip irrigation treatments (2010)
Şekil 1. Damla sulama konularında yaprak ozmotik potansiyelinin değişimi (2010)

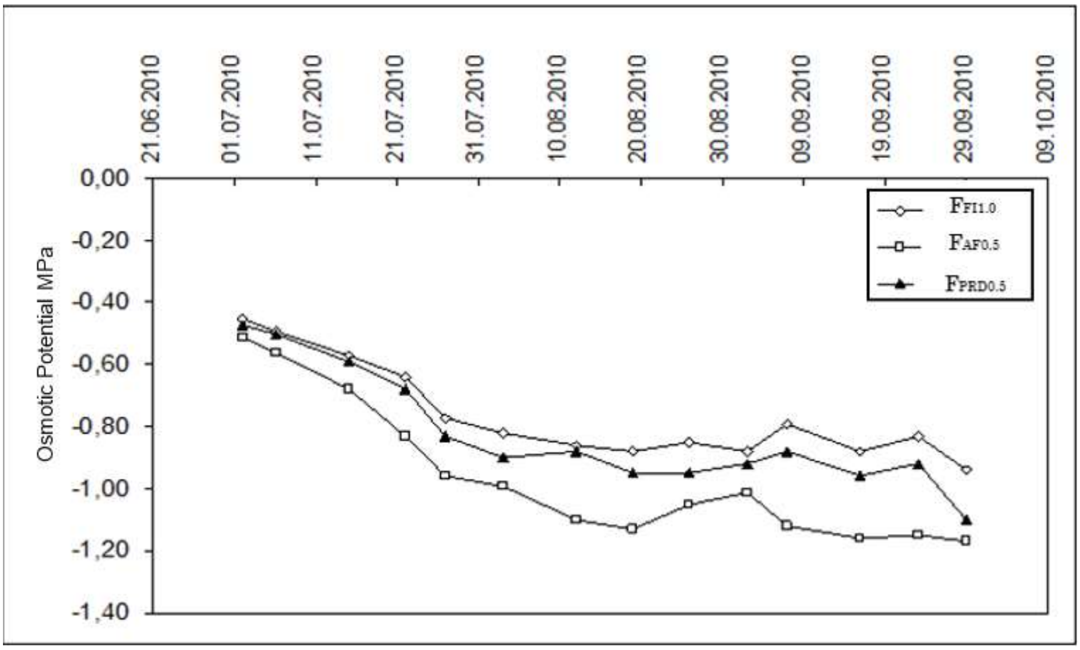

Figure 2. Temporal change of leaf osmotic potential in furrow irrigation treatments (2010)
Şekil 2. Karık sulama konularında yaprak ozmotik potansiyelinin değişimi (2010)

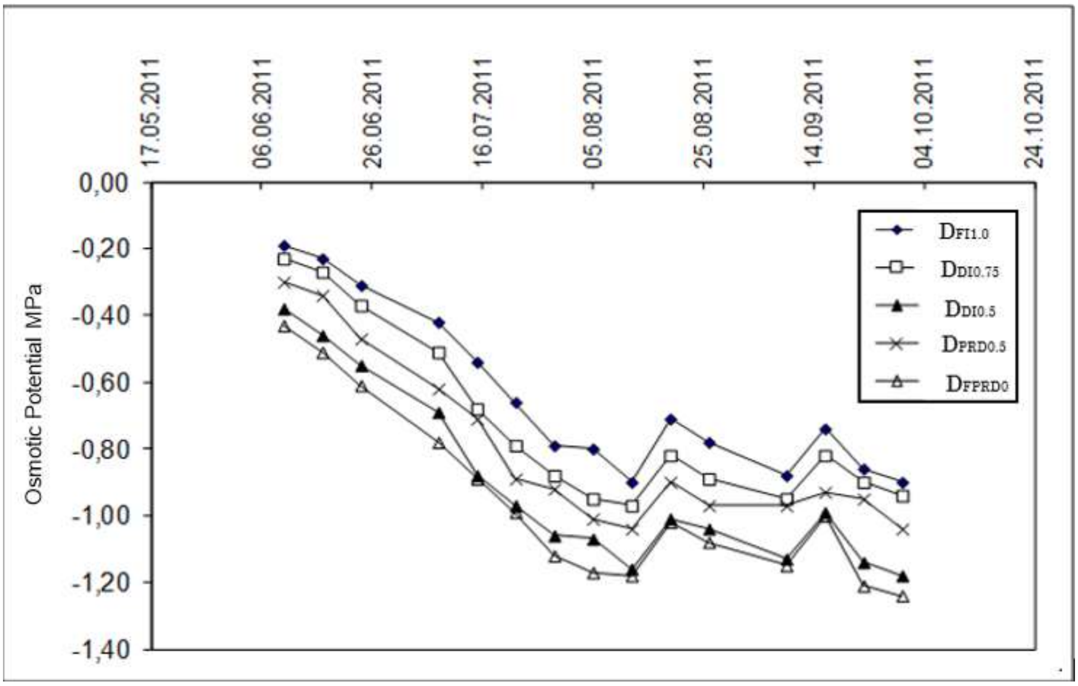

Figure 3. Temporal change of leaf osmotic potential in drip irrigation treatments (2011)
Şekil 3. Damla sulama konularında yaprak ozmotik potansiyelinin değişimi (2011)

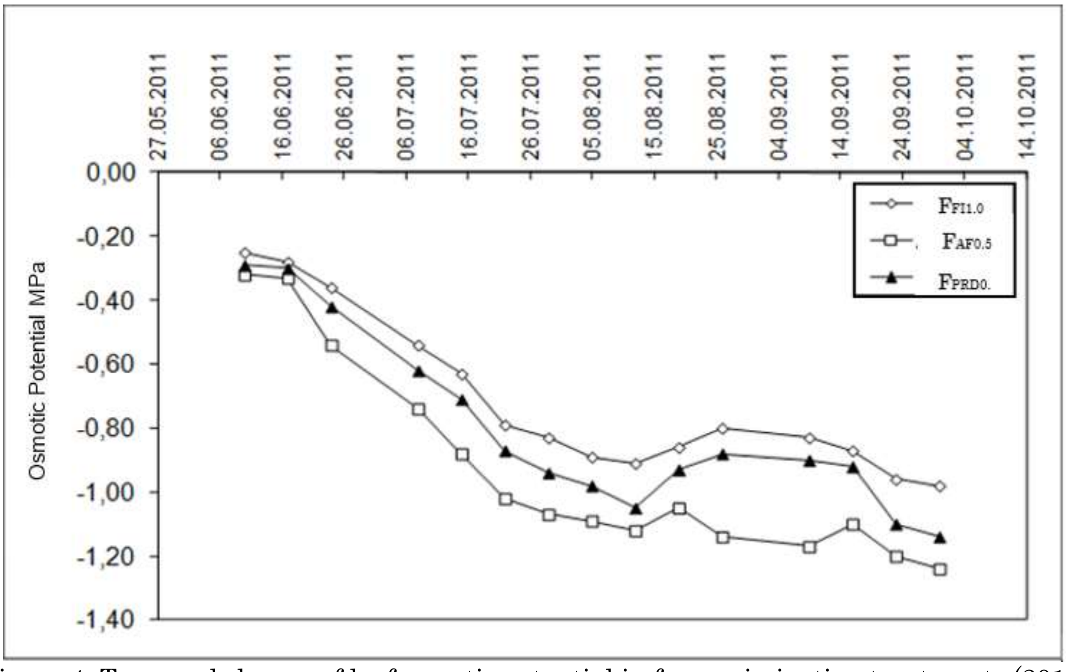

Figure 4. Temporal change of leaf osmotic potential in furrow irrigation treatments (2011)
Şekil 4. Karık sulama konularında yaprak ozmotik potansiyelinin değişimi (2011)

In the 2010 and 2011 growing seasons, K (%) values varied between 2.1-2.5 % and 2.3-2.8%, respectively (Figure 8). Potassium (K) ion consentrations plays an important role in protein synthesis, photosynthesis, stomatal regulation, sugar transport, enzyme activity, and improving yield and quality (White and Karley, 2010; Marschner, 2012; Oosterhuis et al., 2014). Potassium (K) values, which is the most abundant inorganic cation that provides plant growth, tend to increase from the first harvest to the fourth harvest in drip and furrow irrigation treatments in 2010 and 2011 growing seasons. Similar many studies were obtained by Shabala and Cuin, (2008); Walker et al., (2000); Amjad et al., (2014)

CONCLUSION

In this study, the impacts of irrigation methods, irrigation water amount and irrigation strategies (deficit and PRD) are notably significant for acquire higher marketable yields of red pepper under the Mediterranean climatic conditions in Turkey.

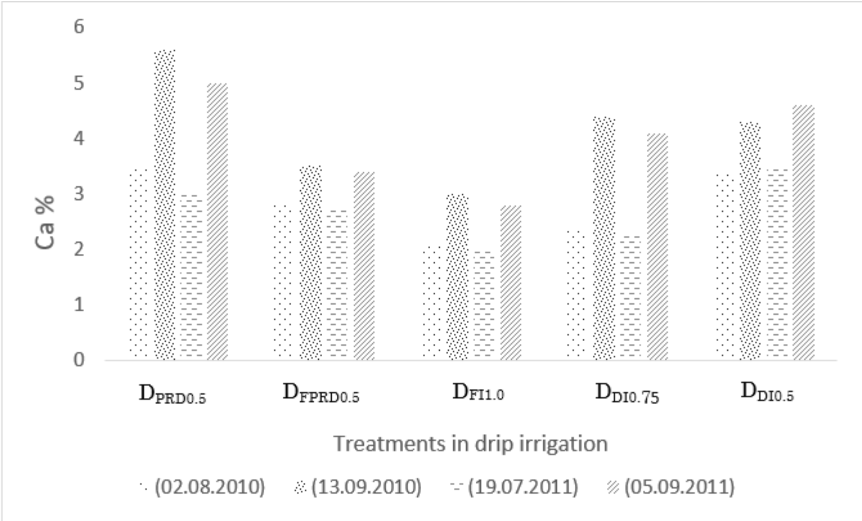

Figure 5. Changes of Ca ion concentrations in leaves in drip irrigation treatments (2010-2011)
Şekil 5. Damla sulama konularındaki yapraklardaki Ca iyon konsantrasyonlarının değişimleri (2010-2011)

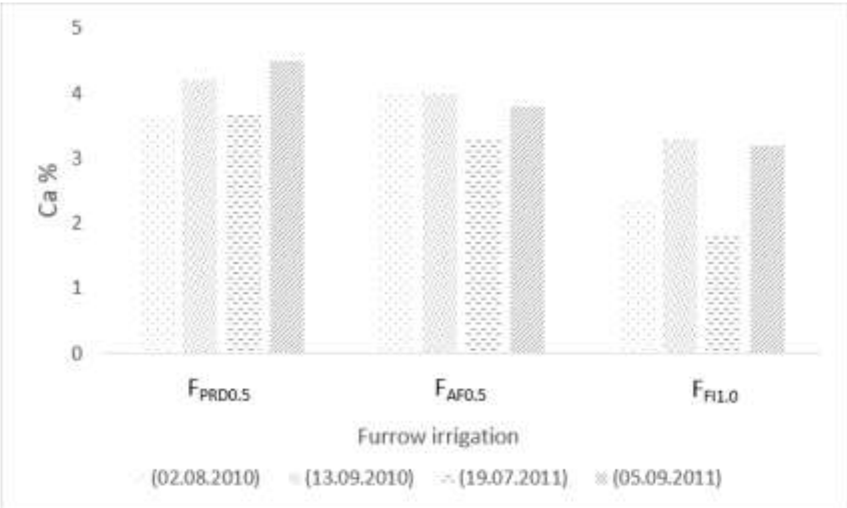

Figure 6. Changes of Ca ion concentrations in leaves in furrow irrigation treatments (2010-2011)
Şekil 6. Karık sulama konularında yapraklardaki Ca iyon konsantrasyonundaki değişimleri (2010-2011)

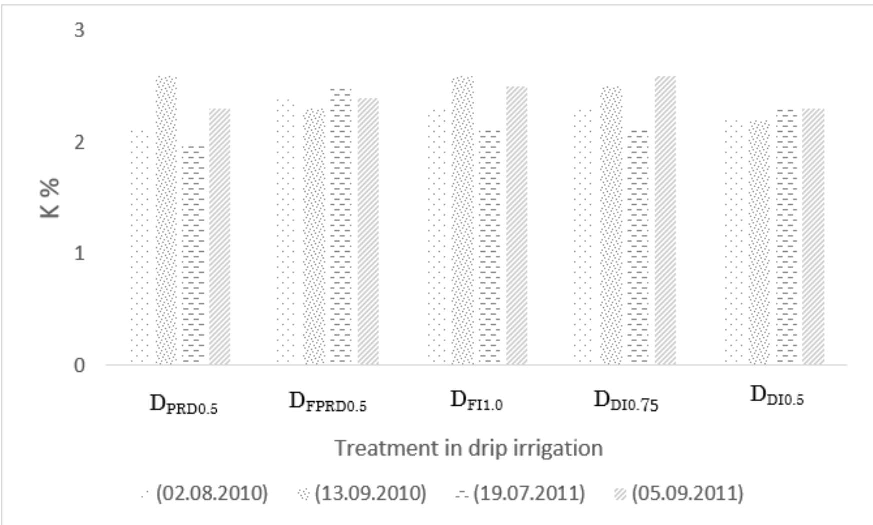

Figure 7. Changes of K ion concentrations in leaves in drip irrigation treatments (2010-2011)
Şekil 7. Damla sulama konularında yapraklardaki K iyon konsantrasyonlarının değişimleri (2010-2011)

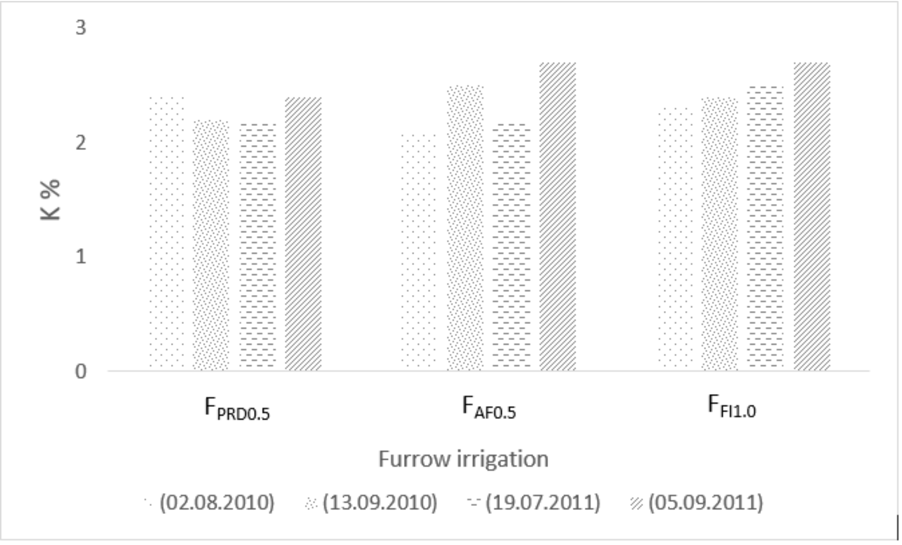

Figure 8. Changes of K ion concentrations in leaves in furrow irrigation treatments (2010-2011)
Şekil 8. Karık sulama konularında yapraklardaki K iyon konsantrasyonundaki değişimleri (2010-2011)

This results revealed that irrigation methods and irrigation levels had a prominent impact on marketable yield of red pepper. The highest yield was obtained from the $D_{FI1.0}$ treatment in drip irrigation which had the highest ET in drip irrigation in both years. Furthermore, the $D_{FI1.0}$ treatment provided in greater quality red pepper yield compared to other deficit irrigation treatments, since the higher irrigation level absolutely impacted yield quality parameters (data not shown). In furrow irrigation, the highest marketable red pepper yield was acquired from the $F_{FI1.0}$ treatment which had the highest ET value. Regarding the rising water shortage conditions in the Mediterranean region, $D_{DI0.75}$ and $F_{PRD0.5}$ reveal to be well alternative to full irrigation for high marketable yields and further high water use efficiency. Different water deficit levels at all growth stages of red pepper, especially PRD treatments, indicated that the ET values of deficit irrigation treatments were significantly reduced compared to full irrigation applications in furrow and drip irrigation methods. The results showed that WUE and IWUE values diminished with enhancement irrigation level in furrow and drip irrigation methods. In order to ensure sustainable agriculture, especially efficient water management strategies should be established in arid and semi-arid regions with insufficient water resources. The findings in this study indicated that $D_{FI1.0}$ and $F_{FI1.0}$ applications, which are irrigated by using 25% of the available water in drip irrigation and 40% of the available water in furrow irrigation and completed to field capacity at 60 cm soil depth are recommended to obtain higher marketable yield and quality of red pepper in the Mediterranean region. While lower osmotic potential values were measured in full irrigation treatments in furrow and drip irrigation plots, higher osmotic potential values were determined in treatments where water stress was determined in both years. In both drip and furrow irrigation, the lowest Ca (%) values were obtained in full irrigation, while the highest Ca values were obtained in limited irrigation with water stress in 2010 and 2011 years. K ion values were generally similar in the first and fourth pepper harvests in drip and furrow irrigation in 2010 and 2011 seasons.

ACKNOWLEDGMENT

The laboratory analyzes were carried out at Departmenf of Horticultural Science of Faculty of Agriculture, Çukurova University.

Author's Contributions

The contribution of the authors is equal.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

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